

Assessment of Actual and Potential Global Warming Effects on Forests of Alaska

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INTRODUCTION: EXTENT AND SIGNIFICANCE OF ALASKA FORESTS

There are 2 major types of forest in Alaska (1) the boreal forest or taiga of southcentral and interior Alaska, and (2) the coastal temperate rainforest of southeast and southcentral Alaska. The boreal forest covers the larger area by far, about 46.2 million ha (114 million ac) versus 5 million ha (12.3 million ac) for the coastal forest (Labau and Van Hess, 1990).

Coastal Forest

Worldwide, the cool temperate rainforest is confined to narrow coastal strips in Chile, New Zealand, Australia, northwest Europe, and northwestern North America, including southeast and southcentral Alaska. It is not naturally abundant on the earth, and a large proportion of the remaining unlogged share of this forest type is found in Alaska. Alaska contains 19% of world total of 26.6 million ha (65.7 million ac) of temperate rainforest, and 38% of the total unlogged area (11.6 million ha) (Ecotrust et al., 1995).

Boreal Forest

The world boreal forest zone makes up about 17% of the earth's land surface area (Bonan, 1992) and increasingly it is being used as a source area for the world timber trade. Of all the major forest regions of the world, the boreal zone supports the lowest density of settled human populations. Only about 12% of the Alaska boreal forest is sufficiently productive to meet the definition of commercial forest land (Labau and Van Hess, 1990). However, the total productive Alaska boreal forest area of about 5.5 million ha (13.5 million ac) is greater than the productive forest land base of many states.

The boreal forest is an important component of the Earth climate system. The stored pools of carbon in boreal forest trees and soils represent a significant share of the total terrestrial carbon reservoir. The release of this carbon to the atmosphere as

carbon dioxide or methane as the result of climate warming could be a major positive feedback loop in future climate warming. The Alaska boreal forest is one of the most intact natural ecosystem regions in the world; nearly all of the Alaska boreal forest still supports most of its native wildlife including free-ranging large predators. Alaska hosts a huge influx of migratory birds that depend on summer breeding grounds in its boreal forests. Many prime wilderness areas are attracting increasing numbers of visitors and their impacts. Large-scale fire management takes place when human habitation or commercially valuable timber is threatened. The Alaska boreal forest supports a small-scale local industry.

CLIMATE TRENDS IN ALASKA

Recently a substantial amount of evidence has begun to accumulate that climate change in Alaska's forest regions has surpassed the range of background variability and is changing systematically in ways that are posing significant challenges to several Alaska forest resources.

Coastal Forest

Mean annual temperature at coastal stations shows a strong cycling trend with a period of about 19 years between peaks (Juday, 1984; Royer, 1993). In the mid 1970s temperatures in Alaska coastal stations increased abruptly to the highest level of the 20th century; even the low period in the temperature cycle that followed was markedly warmer than any similar period in the instrument based record.

Changes in Snow Patterns

In southeast Alaska, the frequency of snow avalanches at low and moderate elevations has declined since the late 1970s in response to climatic warming (more of the winter precipitation falling as rain and less as snow). The result is that mountain hemlock trees are currently colonizing alpine tundra in the region, and the shrub salmonberry (*Rubus spectabilis*) is invading meadows dominated by heather (*Cassiope*)—or sedge (*Carex*) (Veblen

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and Alaback, 1996). A decline in the frequency of severe snow accumulation at low elevations in southeast Alaska has allowed Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) better access to critical winter forage plants. A series of winters with low snowfall is partly responsible for higher winter survival and increased overall population levels of deer. One result may be reduced tree regeneration of the Alaska yellow-cedar (*Chamaecyparis nootkatensis*), a preferred browse species of deer (Hennon, 1992).

Wind Disturbance and Abiotic Stress

Coastal forests of Alaska respond not only to temperature and precipitation, but to wind as well. Wind is the primary disturbance agent in these forests (Veblen and Alaback, 1996). Coastal forests are highly susceptible to wind damage (Harris 1989) due to the combination of shallow root systems, poorly drained soils, and high winds—usually during peak rain intensity (Alaback, 1990). Wind disturbance events typically are small-scaled and involve single trees or small groups of trees—termed canopy gaps (Alaback, 1990; Ott, 1997). However, large-scale tree blowdowns do occur, especially along exposed coastlines (Veblen and Alaback, 1996). The storms that deliver damaging winds to coastal Alaska are produced by the mixing of cold polar air with the warmer air of the North Pacific. A warmer sea surface intensifies the storm system produced (Salmon, 1992). During a period of moderate cooling from 1953-1979 the number of days per year with the fastest mile wind speed >31 mph (moderate gale or stronger) gradually decreased at both Annette Island and Yakutat in southeast Alaska. Since the late 1970s, a period of strong warming in southcentral and southeast coastal Alaska, the number of days with gale winds increased dramatically.

Forest Insects

Biological disturbance agents of coastal forests respond to climate. The western black-headed budworm (*Acleris gloverana*) feeds primarily on western hemlock buds and current year's needles. This insect periodically defoliates large areas of western hemlock-Sitka spruce forest; it causes reduced tree growth, tree top-kill, and some whole-tree mortality (Hard, 1974). Past black-headed budworm outbreaks affected trees over hundreds of thousands of hectares in southeast and southcentral Alaska, where it is one of the most damaging species present (Holsten et al. 1985). Growing season temperature appears to be

a major factor controlling this insect's populations in coastal Alaska (Hard 1974). Large outbreaks are triggered by warm, dry summers (Furniss and Carolyn 1977).

Boreal Forest

Significant climate warming, and drying in certain localities, has been observed in interior Alaska over the last 20 years. For example, the mean daily maximum temperature in the warm season at Fairbanks has been rising sharply (over 3 °C per century) since 1949. Perhaps equally significant, the number of days with the warmest extreme of temperatures, 80° F or warmer, has increased substantially from just over a week in the early 1950s to nearly 3 weeks in the 1990s. The extremes of warm temperatures in the boreal forest are associated with rapid maturation of insects and their population buildups and with moisture stress to trees.

Warm early spring and summer weather is apparently a necessary trigger factor in the production of the infrequent excellent white spruce cone and seed crops (Alden 1985, Zasada et al 1992). Until recently the occurrence of a high number of days with warm temperatures in the early summer would be followed predictably the following year by a white spruce cone crop, unless a crop was already being produced in the trigger year. In the last decade or more, greater numbers of warm days than ever have occurred but crops are not being formed.

A comparison of growing degree days from the most recent (1973-96) 24 years of the Fairbanks Airport climate data compared to the previous 24 years (1949-72) shows a pattern of warmer and extended growing seasons. The average annual total of growing degree days is 10% greater in the most recent half of the Fairbanks record than in the first half. A study of the period 1981 to 1991 claims that an increase in growing season length is detectable from satellite data in the northern hemisphere, concentrated in the area between 45° N and 70° N (Myneni et al 1997).

Moisture Stress

Both annual precipitation and summer precipitation have decreased during the entire 81-year (1906-96) period of record in Fairbanks. Summer precipitation, already marginal for forest growth across much of low elevation interior Alaska, has decreased at rate of 17% per century at Fairbanks. White spruce growth is positively related to precipitation (greater in wet years) and negatively related to temperature (greater in cool years). Since the late 1970s both the precipitation and

temperature index values are moving strongly in an unfavorable direction, warming and drying, for white spruce growth. Trees that are stressed produce more of each annual ring as dense latewood. Figure 16 shows how the density of white spruce latewood closely matches the temperature at the beginning and the end of the growing season. Because recent climate warming has started the growing season earlier and extended growth later, white spruce on productive sites near Fairbanks have become moisture stressed.

The combination of warming and drying are producing severe stress and decreased productivity in boreal forest trees unprecedented in the 20th century (Barber et al., 1997). Elsewhere in Alaska treeline trees (growing at the tree limit along the margin of tundra) that were previously limited only by warmth, are now limited by moisture stress (Jacoby and D'Arrigo, 1995).

Forest Insects

The 1996 aerial survey of areas of major forest damage in Alaska identified 1.0 million ha (2.4 million ac) affected by insects (Holsten and Burnside, 1997). Alaska contains 49.6 million ha (119 million ac) of forest land, of which about 24% is commercial forest land. Roughly speaking then, an area equivalent to about 2% of all forest in Alaska and over 10% of commercial forest displays current or recent significant forest damage. This is an exceptional, if not historically unprecedented, level of forest damage. The ongoing mortality of spruce in southcentral and interior Alaska caused by bark beetles, currently involving 0.46 million ha (1.1 million ac), is the largest forest insect epidemic in North America (Werner 1996).

The widespread outbreak of tree mortality in Alaska from stress-related insects⁸ is also coincident in time with the onset of climate stress (Juday and Marler 1997). In the Bonanza Creek Long-Term Ecological Research (LTER) site in central interior Alaska, the tree-ring growth reduction caused by a 1993-95 spruce budworm (*Choristoneura* spp.) outbreak is unique in the 200-year record, supporting the view that outbreak levels of this insect are a new phenomenon caused by recent climate warming. In the LTER stands monitored snow breakage events in 1989 and 1990-91 triggered bark beetle (*Dendroctonus rufipennis*) attacks that occurred as tree growth was slowing markedly due to warming and drying. This suggests that climate change effects may be multiplicative, as one change (tree breakage

from heavy snowfalls) sets the stage for another (insect outbreaks from damaged trees spread to undamaged stands because of warm weather).

Wildland Fire

Fire is the major natural disturbance agent in the boreal forest. Large scale insect outbreaks can weaken or kill trees over vast areas, often leading to forest fires. Most of the area burned (about 90%) in the Alaskan boreal forest is the result of natural ignition caused by lightning. Figure 18 shows the annual area burned in Alaska. In years with prolonged hot and dry periods of summer weather, Alaska experiences millions of hectares burned, mostly in a few very large fires. Peaks in area burned appear about every 10 years, typically with very little area burned between peak years. The trend in annual area burned in Alaska is related to summer warmth. If the record is analyzed for the period 1955 to 1996 the overall trend represents a moderate decline (34%) of average annual area burned. A portion of the decline possibly may be accounted for by the maximum fire suppression effort in the 1960 and early 1970s. Since the mid 1980s about 80% of Alaska has been zoned for limited or no wildland fire suppression. However, because of the highly cyclic nature of the record of area burned evident in the Alaska record, care should be taken to compare intervals that start and stop at equivalent positions on the approximate 10-year cycle. If estimated fire acreage values typical of the Alaska fire cycle are supplied for 1997-99, then a trend of nearly 100% increase in average annual area burned would appear.

Several factors operating together suggest that a substantial area should burn in Alaska in the next 1 to 4 years. These include: (1) anticipated greater number of periods of warm and dry weather, (2) a cumulative fuel/soil moisture deficit that has developed in the mid 1990s, and (3) extensive areas of dead vegetation. The relative proportion of area burned as a result of human-caused fire is gradually increasing in Alaska as population and developed area increase. A combination of increased human ignition sources, extensive penetration of forest land by suburban and intensified rural development, and prolonged warmer and drier weather set the stage for the highly destructive wildland-urban interface fires. The Miller's Reach-Big Lake fire of 1996 destroyed the largest number of structures by fire in the history of Alaska.

⁸ Insects that either cause stress to trees by their attacks or insects that concentrate their attacks on already stressed trees.

FUTURE CHANGES IN A WARMING CLIMATE

Coastal Forest

Much of the risk to Alaska coastal forest from climate change scenarios associated with global warming involve (1) destructive winds, (2) tree mortality from insect outbreaks, and (3) changes in forest hydrology.

The recent dramatic increase in gale winds in coastal Alaska suggests that the risk of windthrow of trees would be much greater. To date there has not been an apparent increase in the rate of formation of large-scale blowdowns in southeast Alaska corresponding to increased days with storm winds. However, it is possible that canopy gap formation or expansion rates have increased as the number of days with storm winds increased. Trees along clearcut edges in productive, low-elevation forests are more susceptible to wind disturbance, compared to trees in closed canopy forest, for 10 to 15 years following timber harvest. To date, the relationship between the latter 2 types of disturbance and increased days with storm winds has not been documented.

As climate warming occurs, insect populations that were previously restrained by marginal climatic conditions can increase rapidly (Fleming and Volney 1995). Insects can increase much more rapidly than the forest can respond, for example by adjusting the age or species distribution of trees. A transition period of increased tree mortality from insect outbreaks in coastal forest of Alaska would be probable in a warming climate.

Most of the forest streams of coastal Alaska have short and steep watersheds because of the strong, recent geologic uplift that characterizes most of the area. Precipitation has been so abundant and reliable that many streams with small watershed areas are important salmon producers or municipal or industrial water supplies. As the climate warms the forest demands and removes more soil moisture into the atmosphere, reducing ground-water storage available for stream flows. An increase in the number of warm, dry weather intervals under a warming climate would make even more acute the problems from recent low stream flows, such as blockages of spawning fish and lack of municipal water supply.

Ultimately, a number of positive effects on the coastal forest could be associated with a warmer climate. These involve increased average tree growth and other forms of forest productivity,

increased species diversity, and expansion of forest following glacial retreat and colonization of tundra. These adjustments characteristically take some time, but the degree of intactness of the Alaska coastal forest ecosystem insures a high probability of success as long as the magnitude of change does not exceed the degree of adaptability of the organisms, especially of the vegetation. However, if the climate change is of such a magnitude as to allow or require species not currently in or immediately adjacent to the region, then the survival challenge is considerably more severe. A warming of the mean annual temperature that was typical of Anchorage in the 20th century by the amount specified in Weller et al., (1995) would result in a climate that was no longer boreal forest, but a transition type between boreal and temperate hardwood forest. The nearest source areas for seeds and spores to establish such a vegetation type are located over half a continent away in the northcentral U.S. That would be far too distant to make any practical contribution to establishing elements of the temperate forest in Alaska.

Boreal Forest

Much of the risk to Alaska boreal forest from climate change scenarios associated with global warming involve (1) decreases in effective moisture sufficient for forest growth, (2) tree mortality from insect outbreaks, (3) probability of a transition period of large fires, (4) interference with reproduction of white spruce, and (5) changes caused by thawing of permafrost.

The effects of a projected warming of 4° C in summer and 5° C in the winter for interior Alaska (Weller et al., 1995) would depend critically on accompanying changes in precipitation, if any. Warming of the interior Alaska climate without a sufficient increase in precipitation that was effective in supplying water to the forest in the driest part of the year (mid and late summer) would probably transform large areas of productive lowland boreal forest in Alaska and western Canada (Hogg and Hurdle, 1995) to aspen parkland. In aspen parkland conifers are absent and aspen is restricted to stunted patches within a grassland. Aspen parkland occurs in the interior Alaska landscape today as a narrow zone separating steep south bluff grasslands and boreal forest.

One of the characteristic features of the boreal forest is that insect outbreaks are a dominant disturbance factor and that during outbreaks they can cause tree death over vast areas (Juday, 1996; Fleming and Volney, 1995). The risk from future global change to the Alaska boreal forest includes

both (1) increased damage from defoliators and tree-boring insects that have appeared in outbreaks to date, and (2) damage from outbreaks of insect species that have not been observed to produce landscape-level effects on Alaska's forests in the recent past.

The probability of a transition period of large fires in the Alaskan boreal forest is substantial, largely because (A) overall area burned is well correlated with the average summer temperature, and (B) large areas of standing dead forest represent a fuel source that would be difficult to keep from burning once ignited. Fire is an important disturbance agent in the boreal forest and most of the Alaska boreal forest system displays adaptations to it. Fire removes organic accumulations that would otherwise depress site productivity, prepares seedbeds, and renews early successional vegetation important as browse species for many harvested animal species. The main global change issues associated with fire in the boreal forest are the scale, timing, pattern, and intensity of fire. Any of those fire disturbance characteristics could pose unique problems with significant consequences to the forest. Less certain is the fire potential following a transition period of large fires. The new landscape probably would support a significantly lower proportion of conifers and instead large areas of relatively pure hardwood stands that would be relatively fire-resistant. However, a warmer and drier climate might still cause a significant amount of burning in the new landscape.

The disruption of white spruce reproduction in a warmer and more stressful climate would have both significant biological and economic effects on the Alaskan boreal forest. Even the uncertainty over this potential becomes an forest management issue because forests are managed over the relatively long lifespans of the trees. If reproduction of the desired species is not certain in the future, forest management plans may need to be adjusted today. To some degree artificial tree regeneration can mitigate this problem, but then issues of costs and other land management objectives must be addressed.

Changes to the Alaskan boreal forest that would be caused by thawing of permafrost are potentially so extensive and so profound that it is difficult to summarize them. The major pathways of change would involve an unstable transition when surface subsidence from the melting of the ground ice content would alter ground contours and collect, reroute, and alter water. Once the thawing had taken place the site productivity should increase substantially, but the vegetation community

that would develop would probably not be similar that which grew on permafrost (although there is little to base a prediction on). The disappearance of an impervious frozen layer would allow precipitation to infiltrate the ground much more effectively compared to the tendency of permafrost to shed rain immediately. The hydrology of streams and rivers would be considerably different.

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